Free π^0 s for LBNE calibration

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A large sample of exclusively produced π^0s with ~few GeV energy could be useful for calibration of energy scale and reconstruction efficiency. A naturally ocurring source would be π^0s produced by cosmic ray muons through Primakoff effect in water or Liquid Argon.

This exclusive process has been studied in low energy electroproduction on protons at Frascati (Belletini et al.), on Nuclei (HERMES) and even in proton-nucleus collisions (Ferbel).

However it is much better understood in photoproduction and simulations recently done for JLAB measurements, which coincide with the characteristic photon energy from a ~100 GeV muon. Therefore we use here an analysis based on the Weizsacker-Williams(W-W) method. In this method the photon spectrum accompanying the cosmic ray muon is convoluted with the (weakly) energy dependent photoproduction cross section.

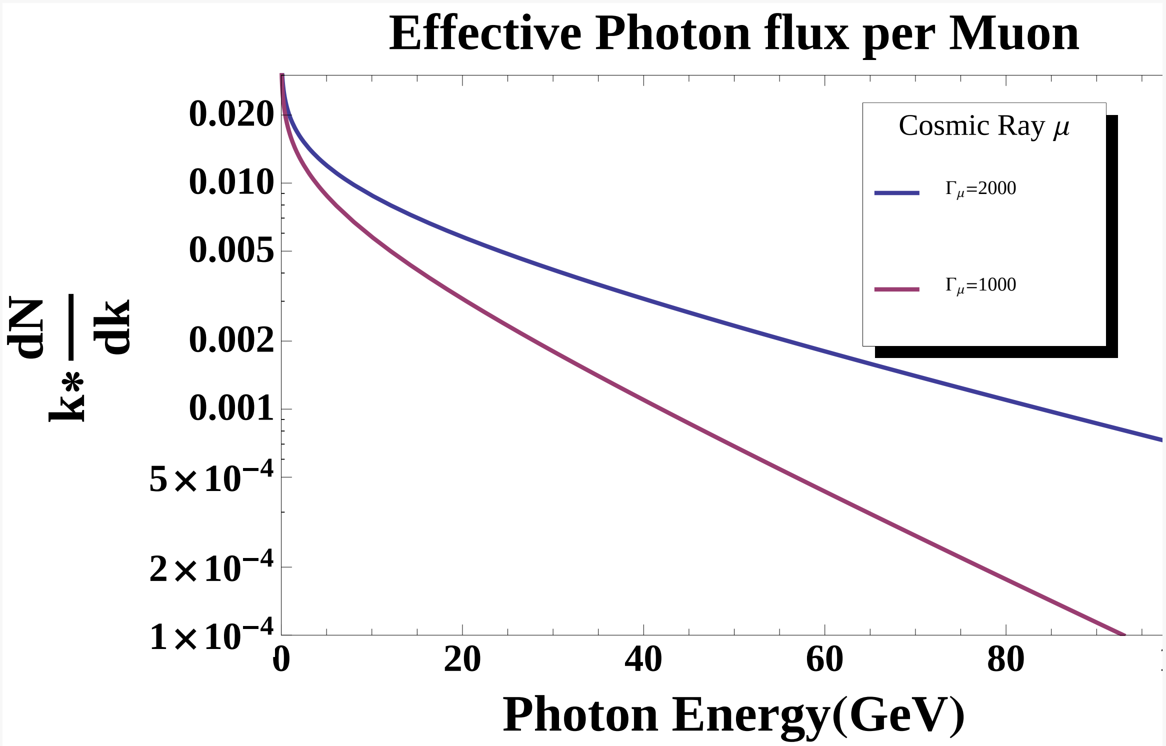
An analysis of the dominant processes of exclusive π^0 production (T. Rodrigues et al.) shows that nuclear coherent production (ie peripheral production by vector meson exchange) is somewhat larger than Primakoff on Argon and may be easier to measure. This process does not have a strong energy dependence. Also the mean photon energy from the W-W spectrum doesn't depend strongly on the muon energy so it may be possible to reliably predict the yield per track even with poor knowledge of the muon spectrum.

To calculate the W-W spectrum we use a form commonly used in the Heavy Ion Ultraperipheral community (A. Baltz et al.) which differs little from Fermi's original development of the Equivalent Photon Approximation . The usual integration over impact parameter from the muon track is cut off at $b = R_{Ar}$ since we are calculationg an exclusive process.

In[167]:=

```
<< Units`
<< PhysicalConstants`
Needs["PlotLegends`"]
Z = 1; A = ElementData["Argon", "AtomicWeight"];
r_A = 1.2 * A^(1/3);
α_EM = FineStructureConstant;
hbarc = PlanckConstantReduced * SpeedOfLight;
hbarc = Part[Convert[hbarc, Giga * ElectronVolt * Fermi], 1];
```

$$\text{DNdk}[k\_, \Gamma\_] := \frac{2 Z^2 \alpha_{EM}}{\pi * k}\left(\frac{k * r_A}{\text{hbarc} * \Gamma} * \text{BesselK}\left[0, \frac{k * r_A}{\text{hbarc} * \Gamma}\right] * \text{BesselK}\left[1, \frac{k * r_A}{\text{hbarc} * \Gamma}\right] - \frac{\left(\frac{k * r_A}{\text{hbarc} * \Gamma}\right)^2}{2}\left(\text{BesselK}\left[1, \frac{k * r_A}{\text{hbarc} * \Gamma}\right]^2 - \text{BesselK}\left[0, \frac{k * r_A}{\text{hbarc} * \Gamma}\right]^2\right)\right)$$



In[185]:=

```
Style[TableForm[
  {{a = Integrate[DNdk[k, 1000], {k, .5, 100}], b = Integrate[DNdk[k, 2000], {k, .5, 100}]},
   {Integrate[k * DNdk[k, 1000] / a, {k, .5, 100}],
    Integrate[k * DNdk[k, 2000] / b, {k, .5, 100}]}},
  TableHeadings → {{"Nγ>0.5 GeV", "<Eγ( GeV)>"}, {"Γμ=1000", "Γμ=2000"}}], 18]
```

Out[185]=

	Γ_μ=1000	Γ_μ=2000
Nγ>0.5 GeV	0.0423594	0.0567329
<E_γ(GeV)>	4.55676	6.5115

In[179]:=

```
σNC = 90(* nuclear coherent on Carbon in μb*);
dΩ = 2 * π * (Cos[.5 Degree] - Cos[2.5 Degree]);
σγ =
 dΩ * σNC * (ElementData["Argon", "AtomicWeight"] / ElementData["Carbon", "AtomicWeight"])^2
σμ = b * σγ
ρLAr = 2 * 10^22;
Nkmweekhz = 10^5 * ρLAr * σμ * 10^-30 (.6 * 10^6)
```

Out[181]=

```
5.71584
```

Out[182]=

```
0.324276
```

Out[184]=

```
389.132
```

The 0.3μb exclusive π^0 production cross section is a significant fraction of the total muon nuclear interaction cross section.

There are roughly 0.1% exclusive π^0's per km of track length. If the cosmic muon flux is of order 0.1-1 Hz then several 1000 exclusive π^0 ' s could be detected in a week. These have very distinctive properties since they are produced at an angle of

$\theta_{peak} \sim 2/(k * R\_Ar) \sim 2/(E\_\pi^0 * R\_Ar)$

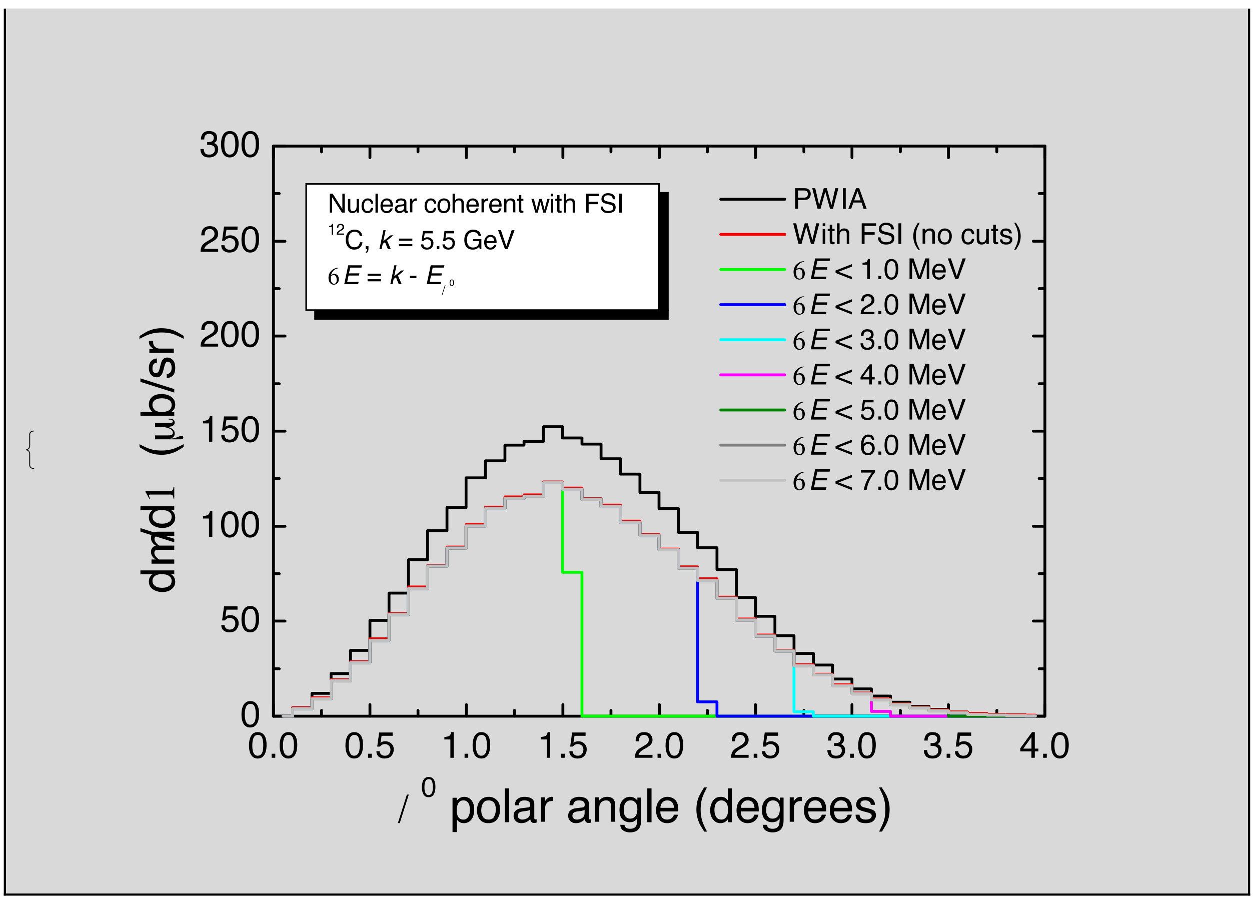
These should be easier to detect than Primakoff produced π^0 s which are closer to the beam direction and have smaller production cross section. Incoherently produced π^0 s have a broader angular distribution and wouldn't be a significant background at this angle.

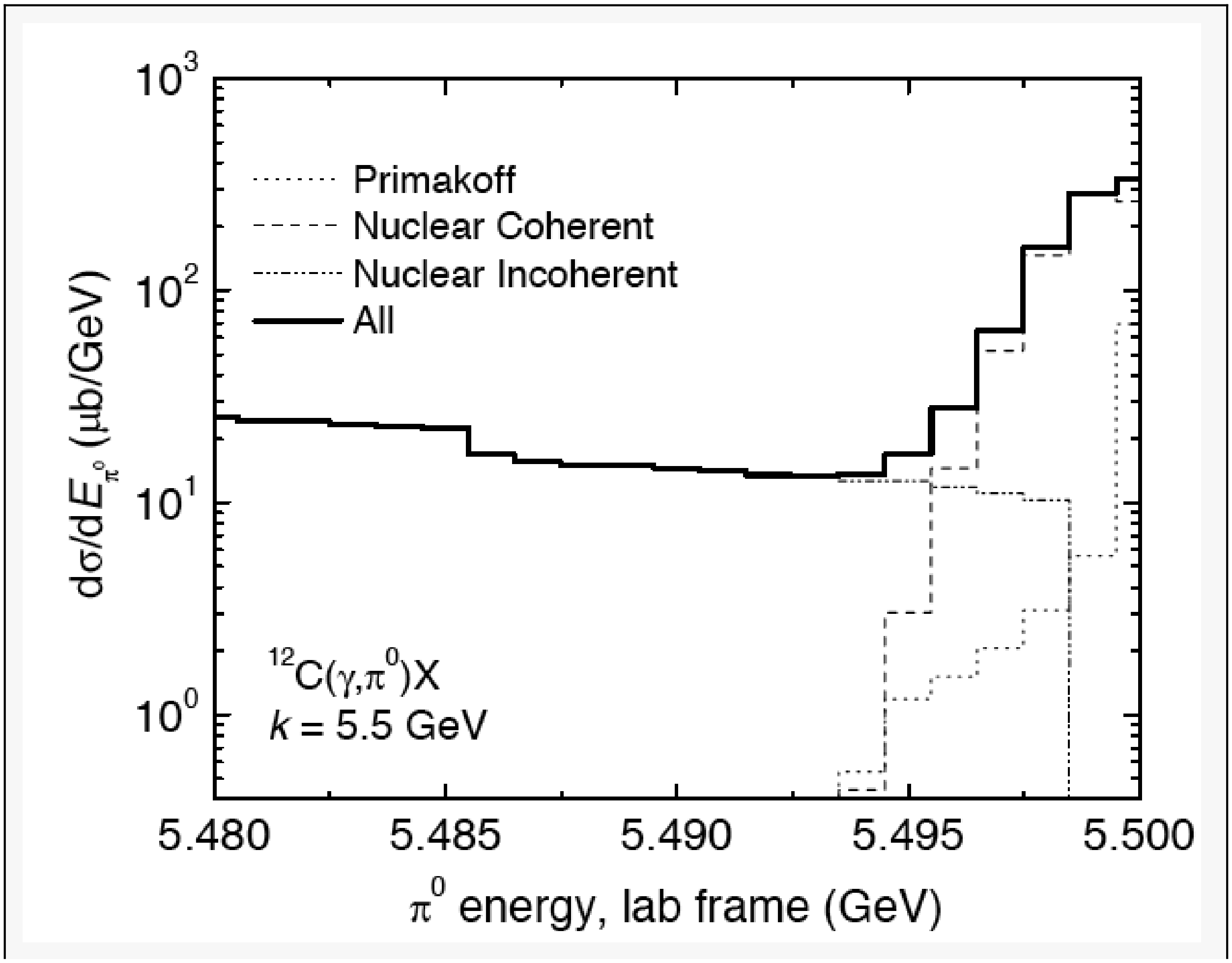
Bibliography:

T. Rodrgues et al. "The nuclear matter effects in π0 photoproduction at high energies", Braz. J. Phys. vol.36 no.4b São Paulo Dec. 2006.
T. Ferbel, Acta Physica Polonica, B12 (1981) 12.
G. Belletini et al., Il Nuovo Cimento A Volume 40, Number 4 / December, 1965
E.Fermi, "On the Theory of Collisions between Atoms and Electrically Charged Particles" http://arxiv.org/abs/hep-th/0205086v1

Appendix: Photoproduction Cross Sections

The following plots are from Rodrigues et al.





10^3
10^2
10^1
10^0
Primakoff
Nuclear Coherent
Nuclear Incoherent
All
$d\sigma/dE_{\pi^0}$ (μb/GeV)
$^{12}C(\gamma,\pi^0)X$
$k = 5.5$ GeV
5.480
5.485
5.490
5.495
5.500
π^0 energy, lab frame (GeV)